Commission D (Electronics and Photonics) Activity Report

August 2009-November 2009

November 10, 2009

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Commission D discussed the study areas, on which the current 14 committee members should especially focus, and they are as follows:

(1) Device and circuit technology for wireless and fiber-optic systems

(2) Advanced electronic/photonic devices and their integration

(3) Novel materials and their applications

(4) Microwave photonics technology

(5) Terahertz-wave technology

Scientific sessions organized by Commission D at AP-RASC 2010 were proposed based on the above areas.

In Activity Report, Commission D will report each time regarding recent significant progress in the above areas especially in Japan. This time, Professor Tsukamoto of Osaka University reviews the area (4); fusion of radio-wave and light-wave system technologies.

Mobile Network Backhaul Applications of Free Space Optical Link Technology

1. Introduction

As optical technologies are becoming more advanced, free-space optical links (FSOL) applications have been considered as a potential medium to provide short range mobile backhaul links using simple and compact equipment. Free-space optical transmission has advantageous aspects such as rapid deployment and relocation, while it has to be operated under limited link lengths due to the propagation impairments. This report describes the recent development of free-space optical links including radio on free space optical links (RoFSOL).

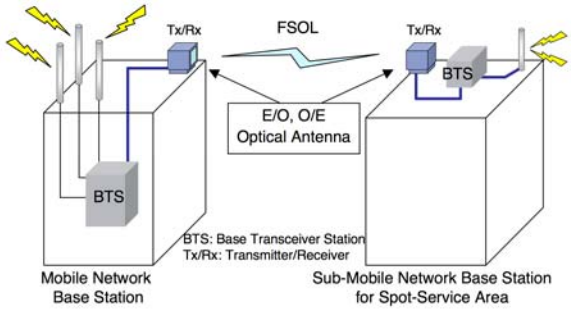
2. Concept of Mobile Network Backhaul with FSOL

Operational aspects of FSOLs are considered in Report ITU-R F.2016 [1]. Mobile network backhaul is recommended as one of the basic applications of FSOL [2]. Figure 1(a) illustrates an application of FSOLs extending a mobile infrastructure, where digital data from a base station for a mobile network are transmitted through a FSOL to a sub-mobile base station for a spot service area. At the optical transmitter (Tx), which includes an electrical-to-optical converter (E/O), optical carriers are intensity-modulated by these digital data. At the optical receiver (Rx), which includes an optical-to-electrical converter (O/E), a received optical signal is detected. The data are input to a radio modem in the base station equipment.

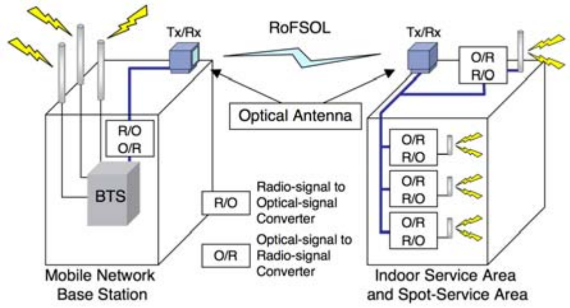
Recent high-speed FSOL systems have achieved some terabits/sec class transmission rates. Reference [3] has reported a 1.28-Tb/s (32 * 40 Gb/s) wavelength-division-multiplexed (WDM) signal was successfully transmitted over a free-space optic (FSO) link. The system used a novel pair of FSO terminals, transparently connected to optical fibers, to transmit/receive the WDM channels over a double-pass FSO path between two buildings (2 * 210 m).

Another type of FSOL, Radio on Free-Space Optical Links (RoFSOL) are also effective as a short link where a conventional wireless/wired link is disadvantageous [4][5]. In RoFSOLs, some Radio on Fiber (RoF) signals are directly transmitted from an optical fiber into air. This can provide a free-space link for various types of wireless services in an optical wireless beam similar to RoF. Since RoFSOLs can transmit some radio-frequency signals independent of their radio interfaces, network operators commonly and flexibly use RoFSOLs as a backhaul network for mobile and other wireless services. RoFSOL technology has been also developed in order to realize a universal backhaul for heterogeneous wireless services.

As shown in Figure 1(b), RoFSOLs can provide another method to extend mobile network infrastructure, where radio signals from a base station analog-modulate an optical signal at a radio-to-optical signal converter (R/O) using a laser diode or an optical external modulator. The modulated optical signal is transmitted through an optical fiber, emitted to the RoFSOL at an optical antenna (Tx), fed into an optical fiber at a receiver optical antenna (Rx), and finally detected at a photodiode in an optical-to-radio converter (O/R). At the output of the O/R, we can again obtain the original radio signals in the radio-frequency band. In RoFSO, therefore, radio signals can be transmitted without any modification in their signal formats. The flexibility and transparency of RoFSOL come from these operations, and from the various types of radio-signal formats that can be transmitted by RoFSOL.



(a)



(b)

Figure 1: (a) Free-space optical links (FSOLs) and (b) radio over free-space optical links (RoFSOLs) for extension of mobile network infrastructures.

3. Radio on Free Space Fiber (RoF), Radio on Free Space Optic (RoFSO), and Radio on Free Space Radio (RoR)

Radio on fiber (RoF) technologies could be a cost effective universal platform for ubiquitous wireless services. RoF networks can be treated as a virtual free space to transport the data link, network, transport and application layers of various wireless services [6]. This layer 1 routing and its benefit can be realized not only by using RoF but also by using radio on free-space optical links (RoFSOLs), which can provide free space for heterogeneous wireless services in an optical wireless link. The same routing can be realized by radio on radio (RoR) networks, in which wireless service signals are frequently converted into microwave, millimeter wave, THz bands and transmitted with non-regenerative repeaters.

By using this transparency for radio signal, radio on fiber links have been applied for mobile networks as feeder links to remote antennas in radio dead zones such as public underground area, indoor, tunnels, and so on[7, 8]. RoFSOLs and RoRs are effective for these feeder links at places where a fiber construction is difficult. A combination of RoF, RoFSOL and RoR is called "hybrid radio access network (H-RAN)"[9] as shown in Fig. 2. H-RAN can be used as an universal and flexible mobile backhaul network for different types of air-interfaces. Air interfaces tends to rapidly change as demands for broadband wireless services increase. H-RAN can easily accommodate a new coming wireless service only by installing a new BTS equipment at center station. Considering trends of future femto-cell operations and fixed mobile convergence (FMC) services, software definable radio network (SDRN) has been also proposed to connect various types of wireless access links, H-RAN and Internet Protocol (IP) based core network [6]

As seen above, RoFSOLs and RoRLs are effective as same as RoF in mobile backhaul networks. Compared with RoRs, the advantages of RoFSOLs are license-free operation and a higher transmission capacity. Moreover, employment of WDM technology can provide mutually independent free space in a optical beam for each of the heterogeneous wireless services. It can also offer an extremely large and transparent transmission capacity to a wireless service signal.

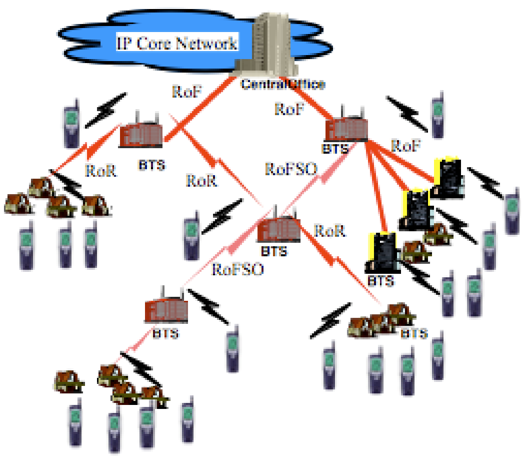


Figure 2: Concept of hybrid radio access network (H-RAN).

4. Radio on Free Space Optical Link Technology

RoFSOLs using WDM techniques system have bee developed to create an effective and quick provision of heterogeneous wireless services for not only urban but also rural areas that have little or no infrastructure for broadband services [4],[5]. In rural areas or developing countries, rich fiber infrastructures have not yet been constructed due to their high cost or the region’s low population. While broadband wireless technologies are rapidly progressing and new services are being offered to urban areas quickly, these new services have been under-represented in rural areas for a long time. To solve such a gap in broadband services, RoFSOLs without fiber or a combination of RoF and RoFSOLs are suitable as a universal backhaul link and a universal access point for heterogeneous wireless services. The latter combination is applicable for a relatively longer backhaul link, where fiber construction often becomes difficult due to rivers, roads, or some other geographical conditions.

In this case, an RoFSOL is effective to relay between two RoFs or to extend RoF without any signal conversions, because RoFSOLs can transmit an optical signal from an optical fiber into air, and directly feed it into another fiber.

Figure 3 illustrates the technical features of a RoFSOL system. Conventional FSOL systems shown in Fig. 3 (a) have been adapted for each of the digital data transmissions with different data rates such as Ethernet, mobile phone entrance, digital CATV, and so on. Recently, next generation FSOL systems shown in Fig 3 (b) [10], have realized a stable 10 Gbps WDM FSO transmission. Therefore, a protocol-free digital FSOL with the almost same performance as an optical fiber has been realized.

RoFSOLs make it possible to extend FSOL flexibility and transparency from the physical layer to the application layers, thus enabling heterogeneous wireless services. As shown in Fig 3 (b), the RoFSOL is capable of the transparent transmission used for cellular phones, two types of wireless LAN, and digital terrestrial broadcasting by using WDM optical wireless channels. Future wireless services can be accommodated by attaching their modems to the central station. The optical transceiver employs direct optical amplification, the emission of a RoF signal into free space, and the direct focusing of the received optical beam into the core of a single-mode fiber. An optical fine beam tracking system achieves a stable and reliable FSOL against weather conditions and scintillation at an atmospheric channel of more than 1 km. Similar systems have been reported in [11] and [12].

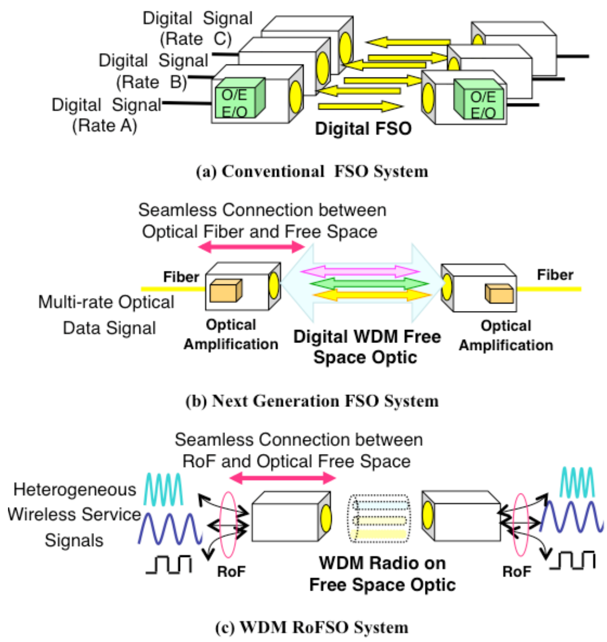


Figure 3: Features of RoFSOL system.

5. Summary

This report introduced the use of FSOLs in relation to backhaul applications as well as its technology trend, including the recent development of RoFSOLs. FSOLs are becoming useful media for backhaul applications for particular cases in which immediate deployment of a conventional wireless/wired link is disadvantageous. RoFSOLs using WDM technology can provide shared backhaul for flexible deployment of various wireless services operating in different radio frequency bands.

References

[1] "Fixed Service Applications using Free-space Optical Links", ITU-R, Report ITU-R F.2106, 2007.

[2] K. Tsukamoto, A. Hashimoto, Y. Aburakawa, and M. Matsumoto :"The Case for Free Space - Explorng the Prospect of Free-space Optical Links for Backhaul Applications-", IEEE Microwave Magazine, Vol. 10, No.5, pp. 84-92, August 2009.

[3] E. Ciaramella, Y. Arimoto, G. Contestabile, M. Presi, A. D'Errico, V. Guarino, and M. Matsumoto, "1.28-Tb/s (32 40 Gb/s) Free-Space Optical WDM Transmission System," IEEE PTL, Vol 21, No. 16, pp. 1121-1123, 2009.

[4] K. Tsukamoto, et. al. ,"Development of DWDM Radio on Free Space Optic Link System for Ubiquitous Wireless", Technical Digest of AP-MWP2007, Vol.1, No.1, April 2007.

[5] K. Kazaura, et. al. ,"Experimental Evaluation of a Radio-on-FSO Communication System for Multiple RF Signal Transmission", Proc. of SPIE, Vol. 7199, pp. 719907-1-12 , January 2009.

[6] S. Komaki :"Microwave Technologies for Software Radio Networks", Proceedings of APMC2003, Vol. 3, No. FC7-1, pp. 1780-1785, November 2003.

[7] Y. Ito and Y. Ebine, "Radio on Fiber System for Triple Band Transmission in Cellular Mobile Communication," IEEE International Topical Meeting on Microwave Photonics (MWP2000) Tech. Dig., TU1.2, pp. 35-38, Sep. 2000.

[8] Y. Horiuchi, "ROF Application to 3G Mobile Systems in Offices and Outdoors," International Topical Meeting on Microwave Photonics (MWP2005) Tech.Dig., p. 3, Oct. 2005.

[9] S.Komaki, "Software Definable Radio Networks for Ubiquitous Network Applications," ASTAP Wireless JEG (MMCS-EG) 9, ASTAP08-FR14-EG-MMCS-04_RadioNetworks , Kobe, June 2008.

[10] K. Kazaura, et. al. ,"Experimental Performance Evaluation of Next Generation FSO Communication System," AP-MWP 2006, Vol. 1, pp. 289-292, April 2006.

[11] Hakki H.Refai, et al.,“The Transmission of Multiple RF Signals in Free Space Optics Using Wavelength Division Multiplexing”, Proceedings of SPIE, Vol.5793, pp 136-143, 2005.

[12] G. Katz, S. Armon, P.Goldgeier, Y. Hauptman and N. Atias, “Cellular over Optical Wireless Networks”, IEE Proc.-Optoelectron.,Vol. 153, No.4, pp 19.